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MARINE PHYSICAL LABORATORY
of the Scripps Institution of Oceanography
San Diego, California 92152

SURVEY OF CHASE DISPOSAL AREA (NITNATOW)

F. N. Spiess and S. M. Sanders

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A deep towed submersible instrument platform (FISH) equipped with side-looking sonar, magnetometer and cameras was used to locate and document the wreckage sites of five munitions laden ships which had been detonated in the process of munitions disposal. Geographical positions were determined first with reference to a network of acoustic transponders planted for this purpose. Subsequently the latitude and longitude of the transponders were determined by correlating the towing vessel's position as determined by satellite navigation with the corresponding position relative to the transponder network. Wreckage sites were then assigned conventional geographical coordinates. Photographs were taken of all sites and, for comparison purposes, of undisturbed sea floor.

NARRATIVE

The deep towed submersible vessel (FISH) of the Scripps Marine Physical Laboratory[1] was employed in a thorough survey of a 20 kilometer square centered approximately upon latitude 48°15'N, longitude 127°00'W. Bathymetric records indicate that the topography was essentially flat at about 2600 meters and showed the smoothness of texture to be expected on a deep sea fan.[2]

The expedition succeeded in locating the wreckage of five ships utilized in munitions disposal. The survey tracks and site locations are shown in Fig. 1. Acoustic and photographic data indicate that the ships were, for all practical purposes, pulverized upon detonation of their explosive cargo. Few large distinguishable pieces were found (Fig. 4, time 1112, range 200 fm (365 m) and Fig. 5, time 2245, range 300 fm (545 m)). The preliminary report of this survey[3] reported a similarity in pattern of distribution of debris among the five sites based upon the observed data in Figs. 2 through 6. More extensive reduction of the data confirms the initial analysis but with some significant differences which are described in later paragraphs along with the method of analysis.

The speed of the FISH in each of these figures was as follows

Figure 2	1.28 knots	(0.66 m/sec)
Figure 3	1.81 knots	(0.93 m/sec)
Figure 4	2.02 knots	(1.04 m/sec)
Figure 5	1.71 knots	(0.88 m/sec)
Figure 6	1.22 knots	(0.63 m/sec)

The distance along the record between the 15 minute marks thus ranges between 565 and 935 meters. Quite significantly the view presented in each of these figures does not necessarily encompass the entire outline of the wreckage area concerned, although in some cases the correlation is amazingly close. The recorders were operating on a 1.25

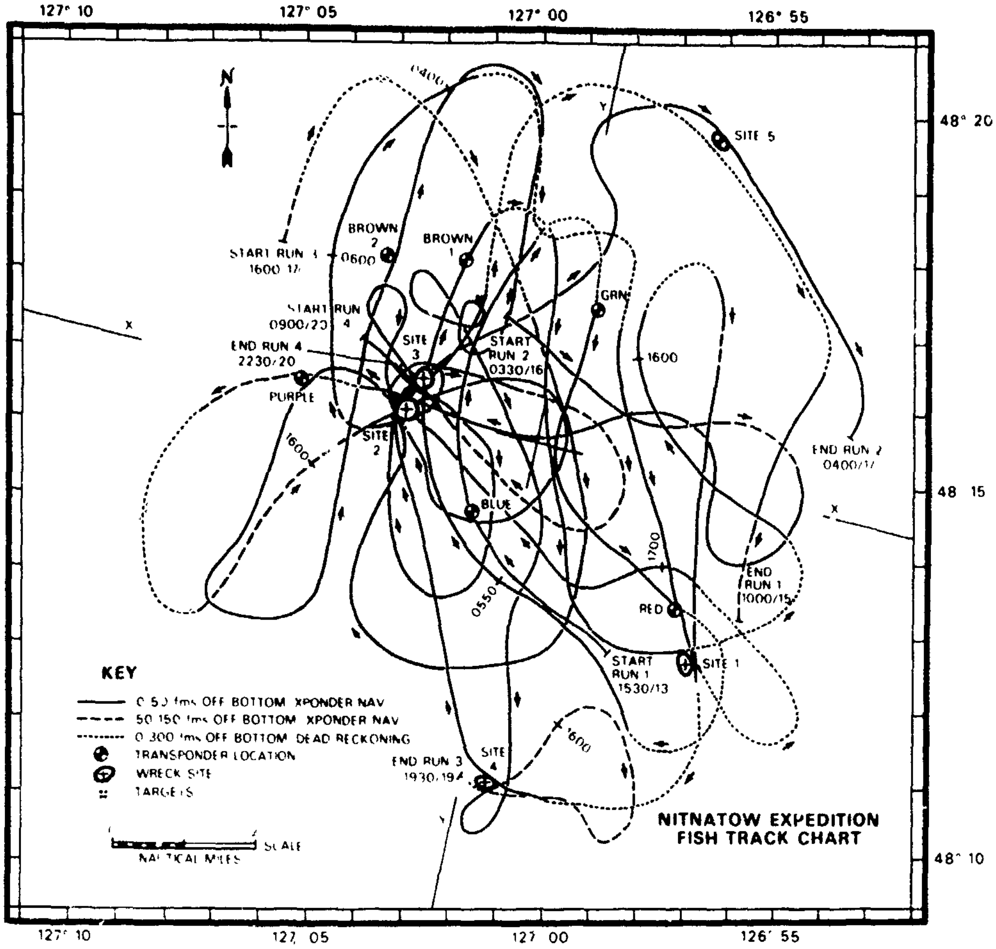


Fig. 1. FISH track chart.

second ("500 fathom") sweep, thus the scale lines represent 25 fathoms (46 m) increments of slant range from the FISH using a sound speed of 800 fathoms/sec (1463 m/sec).

Figures 7 through 13 are indicative of the effectiveness of the underwater explosion in reducing the carrying vessels to rubble and of the distribution of the residue. The sequence of photographs was selected to illustrate the appearance of the sea floor as the FISH passed into, through and out of Site 3. The approach to the site in this sequence traversed the area between adjacent Sites 2 and 3. Figures 14 and 15 are the corresponding side-looking sonar records.

Navigation was with reference to a network of acoustic transponders[4/] specifically placed for this operation. Initially, five transponders were emplaced, but failure of one necessitated employment of a sixth unit. Two of these units, designated Purple and Brown 2, were left on site and served as initial reference points for a subsequent survey by another group. These units were short-lived; however data were taken to make possible the accurate determination of the geographical coordinates of the sites. Both towing vessel (henceforth referred to as ship) and FISH positions were fixed by ranging to the transponders. In addition, a satellite navigator was in continuous use determining the ship position in standard geographical coordinates. Lack of accurate speed information due to an inoperative ship's underwater log as well as relatively inaccurate ship course information necessitated post-expedition recomputation of satellite positions. This has been done using speed and heading information generated by calculating ship positions relative to the transponder network.

Operations commenced early on 13 July 1971 with the launch of the first transponder and were completed on 20 July 1971. A series of four detection runs was conducted (all times GMT):

Run 1	1530 13 July - 1000 15 July
Run 2	0330 16 July - 0400 17 July
Run 3	1600 17 July - 1930 19 July
Run 4	0900 20 July - 2230 20 July

The actual track of the FISH is as shown in Fig. 1. The pattern reflects the multiple objectives (refinement of navigation, search, side-looking pattern delineation, photography) which one has in mind during an operation of this kind, and the manner in which these interact with the realities of seagoing work (particularly wind and current, but also transponder shadow zones, system noise related to towing speed and the times required to lower or retrieve the FISH). The level of search coverage can be estimated by visualizing a sweep width of about 460 meters (1/4 nautical mile) on each side of the track.

The magnetometer, trailing 30 meters behind the FISH, was in nearly continuous operation from commencement of the first run through the conclusion of the final run. During the first half of the survey camera operation was found to interfere with satisfactory performance of the magnetometer and consequently the latter was secured for camera runs during the later stages of the survey. Nevertheless, there was possible indication that passage over a wreckage site could be correlated with observed anomalies. The recording system for the magnetometer only logged the last three (or four depending on switch setting) digits of the magnetometer counter and hence care has to be taken to differentiate between spurious counts caused by equipment interference and valid but rapidly changing magnetic field measurements caused by localized objects. Careful and close examination of the original data suggests that the following interpretation is highly plausible.

Referring to Figures 6, 14 and 15, the horizontal white lines indicate FISH positions at the instant when the magnetometer was polarized. The time between successive polarizations is 1.5 minutes. During the period 0200-0215 15 July (Figs. 14 and 15) the FISH was travelling along the track at an average speed of 0.73 m/sec. Thus, the magnetometer was recording the anomaly at a position 40 seconds behind the FISH. This position is approximately one-half the distance between the horizontal white lines. At 0204 (third line) the magnetometer had just started to enter the area of heavy wreckage concentration; the indication was 55584 gammas (42255 counts). On the next three polarizations (0205.5, 0207, and 0208.5) the indications were 54698, 54571 and 55277 gammas (42940, 43040, 42490 counts) respectively. By 0210 the level had dropped to 55710 gammas (42160 counts); the magnetometer was approximately at the edge of the wreckage site. By 0215 the level had dropped to the prevailing background of approximately 55855 gammas (42050 counts). The three highest readings correspond to passage through the heavy concentration at the site center. Taking into account the noise introduced by operation of the photographic apparatus, these readings still yield anomalies of 900-1300 gammas. The FISH was at an altitude of approximately 13 meters from the bottom. Considering the geometric configuration of the site, the magnitude of any associated anomaly can be expected to decay at a rate inversely proportional to a factor between the square and the cube of the distance to the center. The observed diminution of the anomaly during this run is not inconsistent with this hypothesis. Inspection of Fig. 6 (during which period the magnetometer trailed the FISH by 32 seconds) indicates that the magnetometer passed abeam of the site center (at a distance of approximately 280 meters) at 0632.5 15 July; the corresponding anomaly is at most 5 gammas and, based upon the above discussion, is consistent with the size anomaly to be expected at 280 meters.

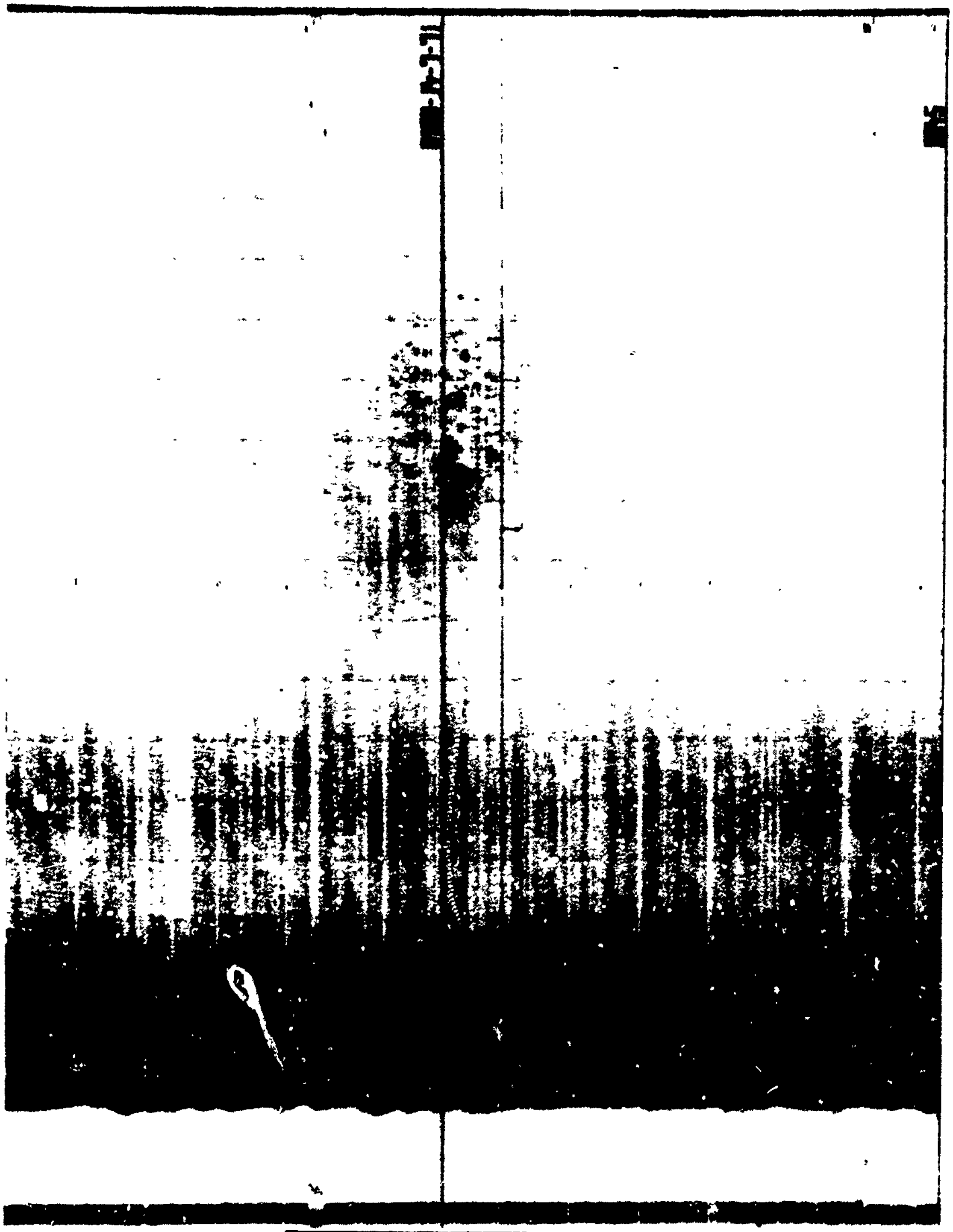


Fig. 2. Site 1, right side-looking sonar, 14 July 1971, time 0100.

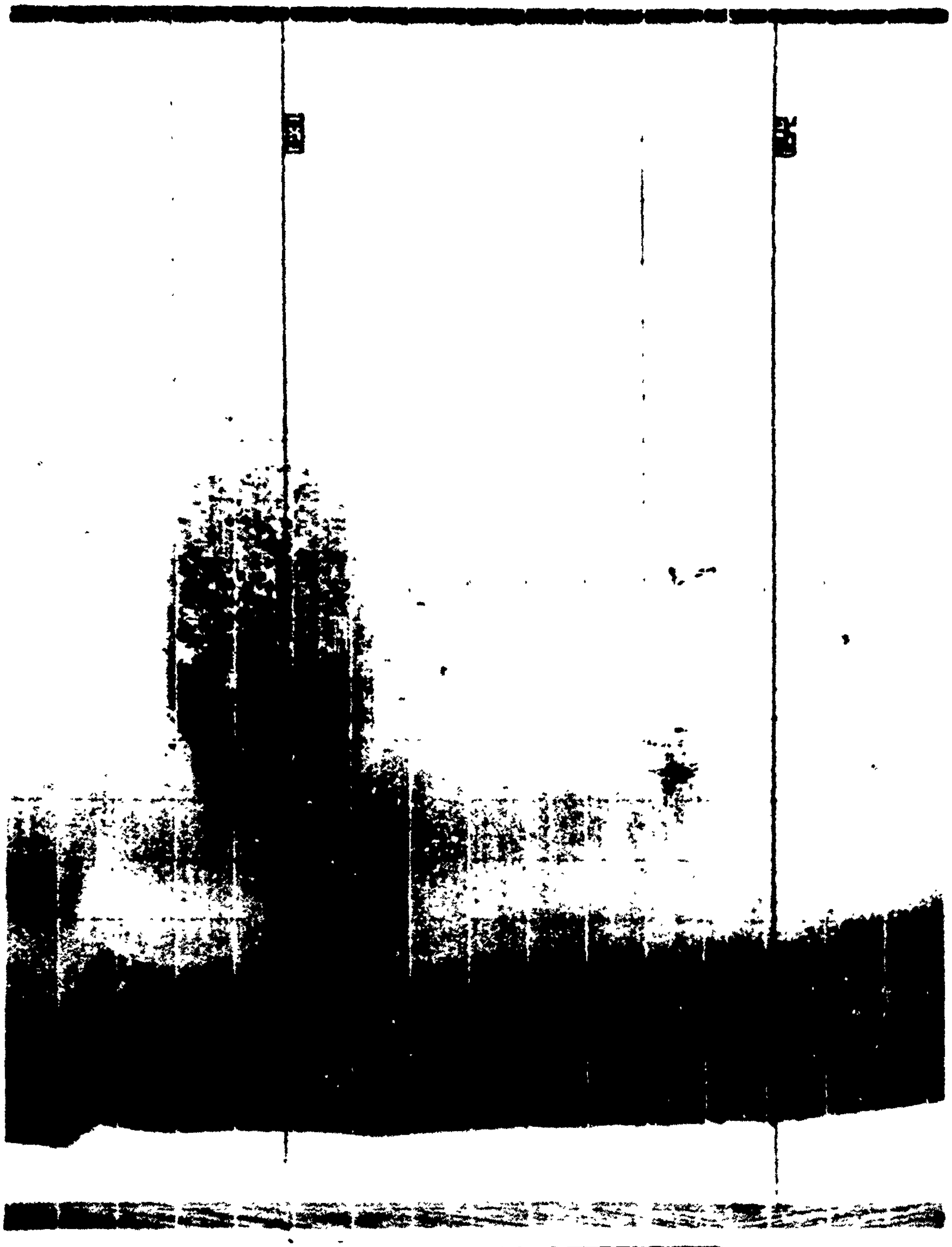


Fig. 3. Site 2, left side-looking sonar, 16 July 1971, time 0630.

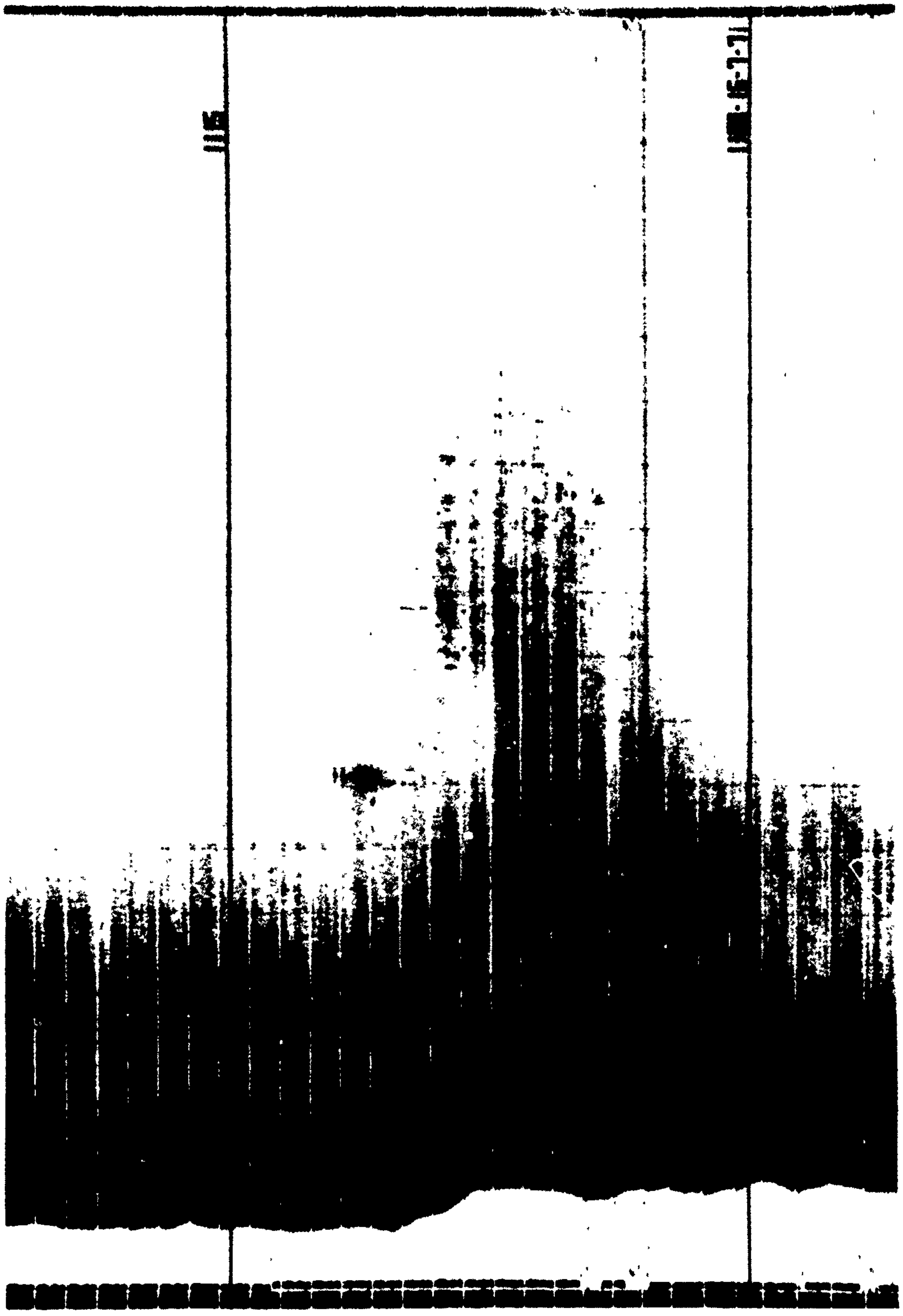


Fig. 4. Site 3, right side-looking sonar, 16 July 1971, time 1100.

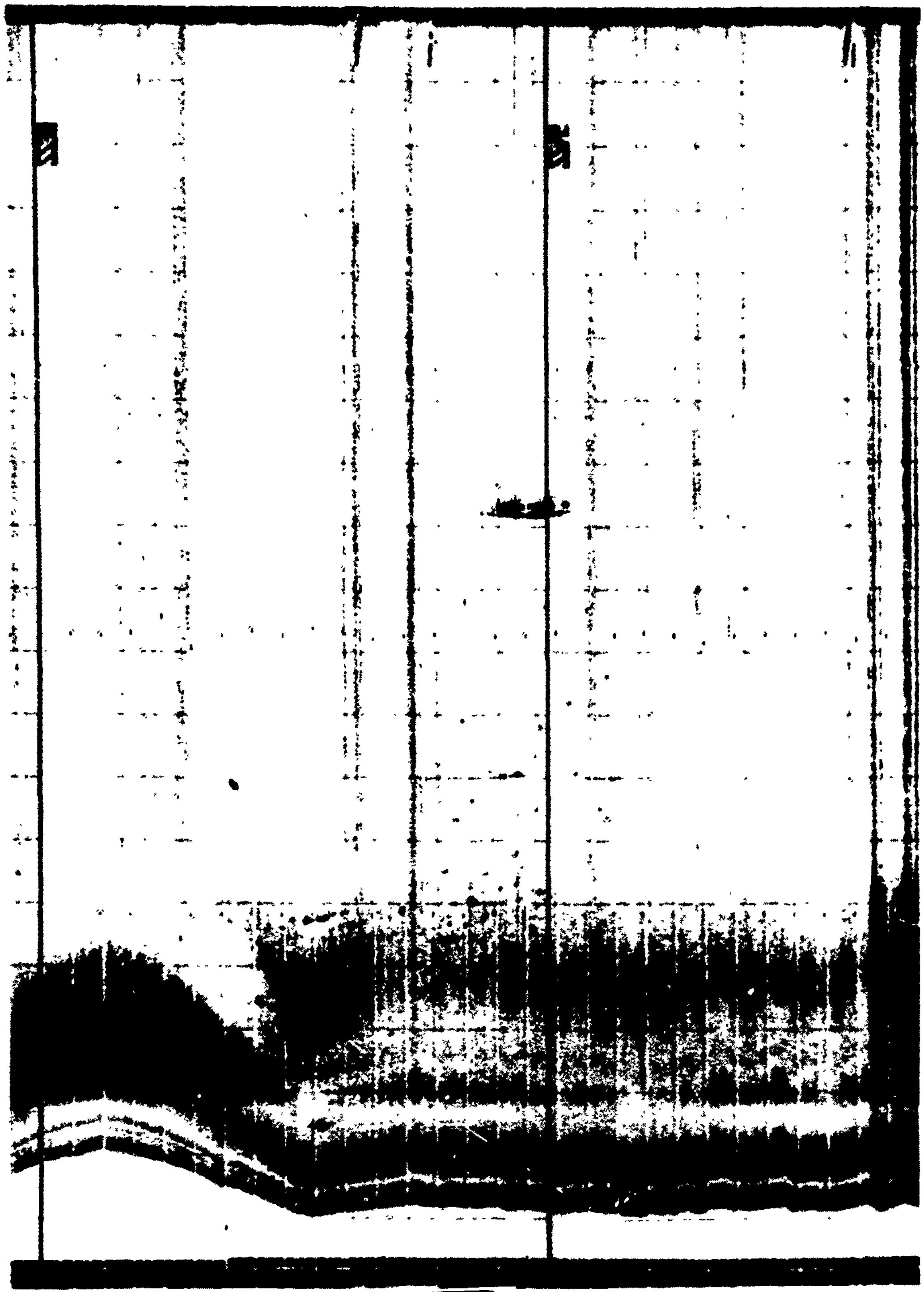


Fig. 5. Site 4, left side-looking sonar, 14 July 1971, time 2245.

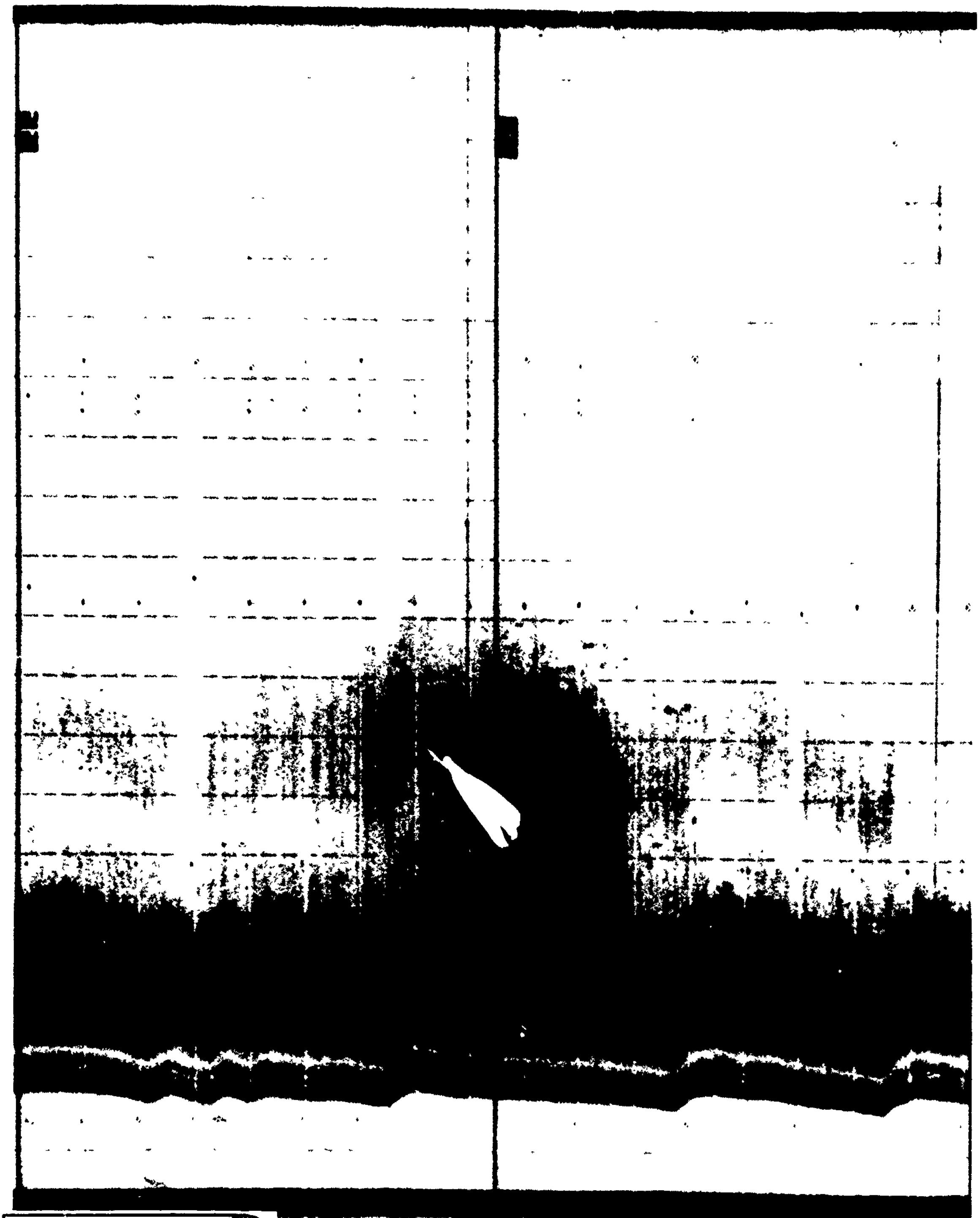


Fig. 6. Site 5, left side-looking sonar, 15 July 1971, time 0630.

Fig. 7. Site 3, Run 1B, 0202, 15 July 1971.

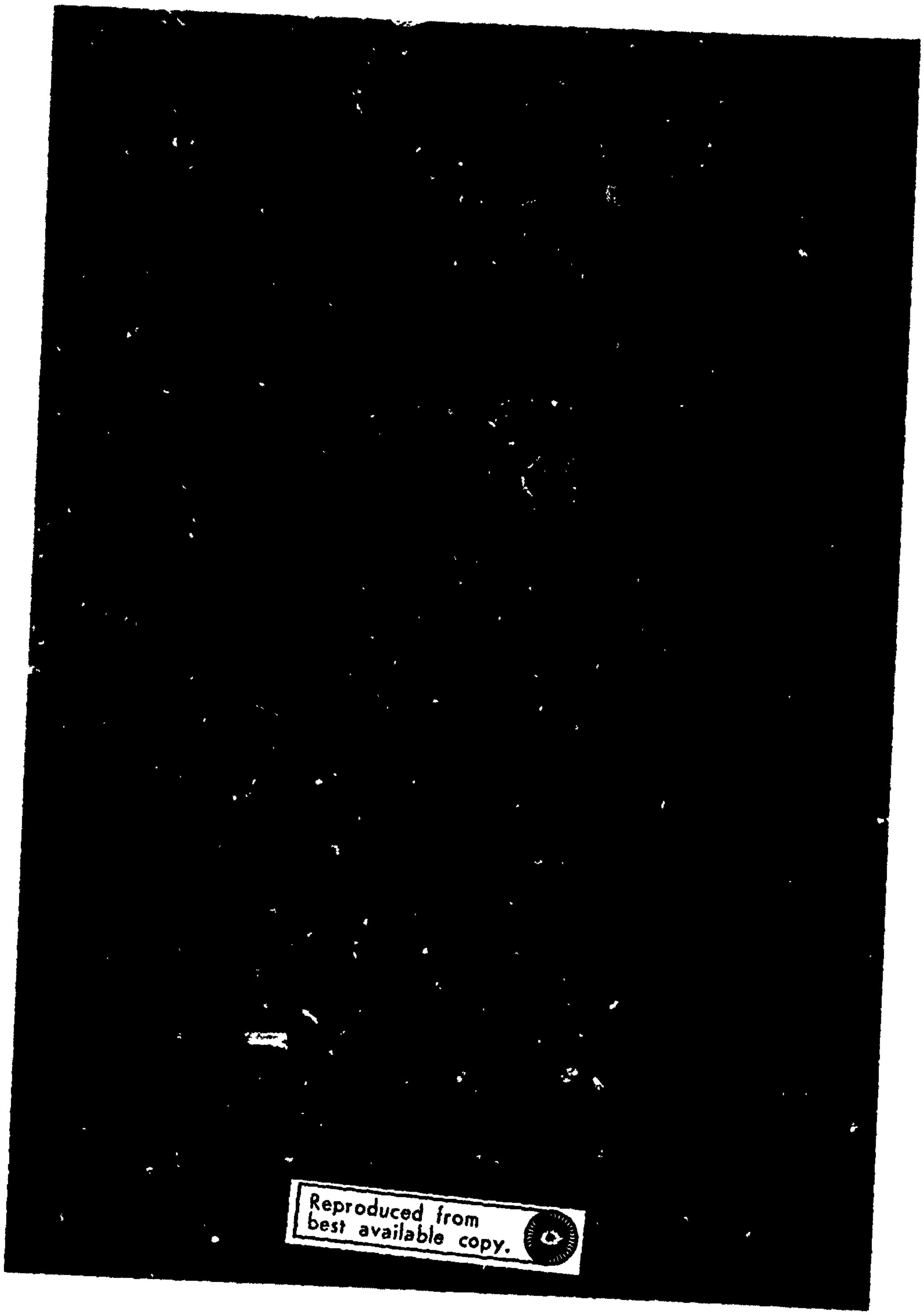


Fig. 8. Site 3, Run 1B, 0204, 15 July 1971.

Fig. 9. Site 3, Run 1B, 0208, 15 July 1971.

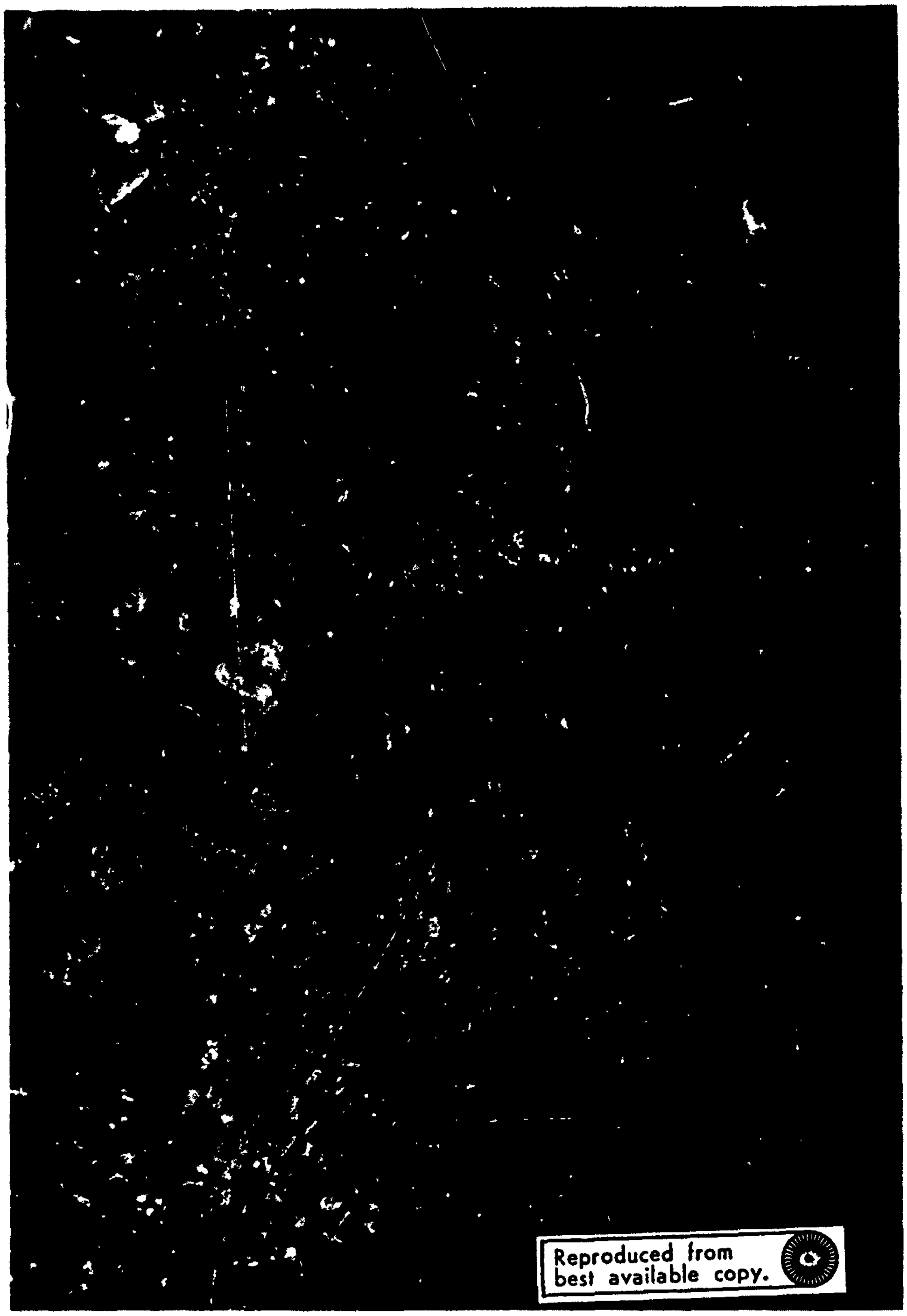


Fig. 10. Site 3, Run 1B, 0210, 15 July 1971.

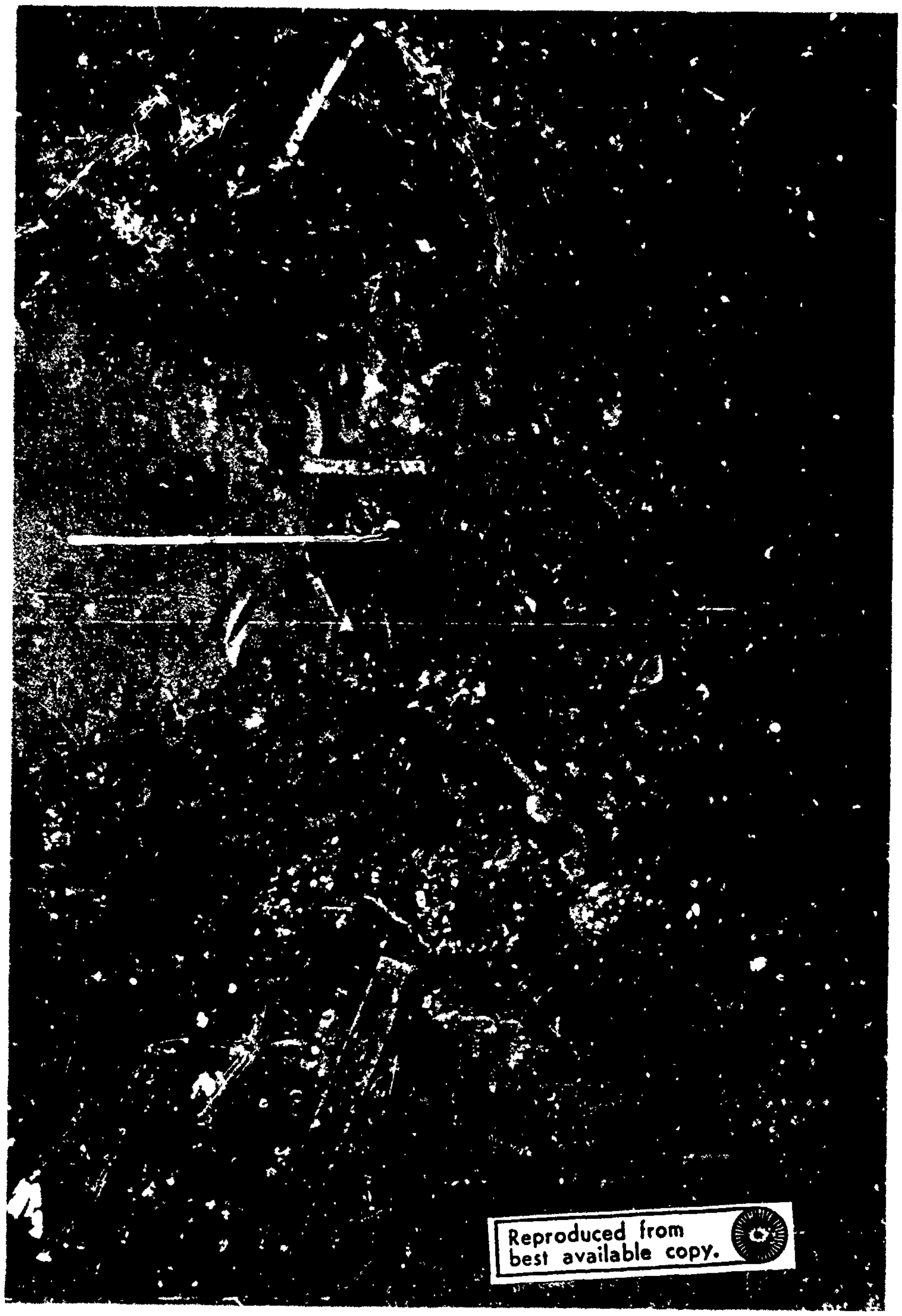


Fig. 11. Site 3, Run 1B, 0212, 15 July 1971.

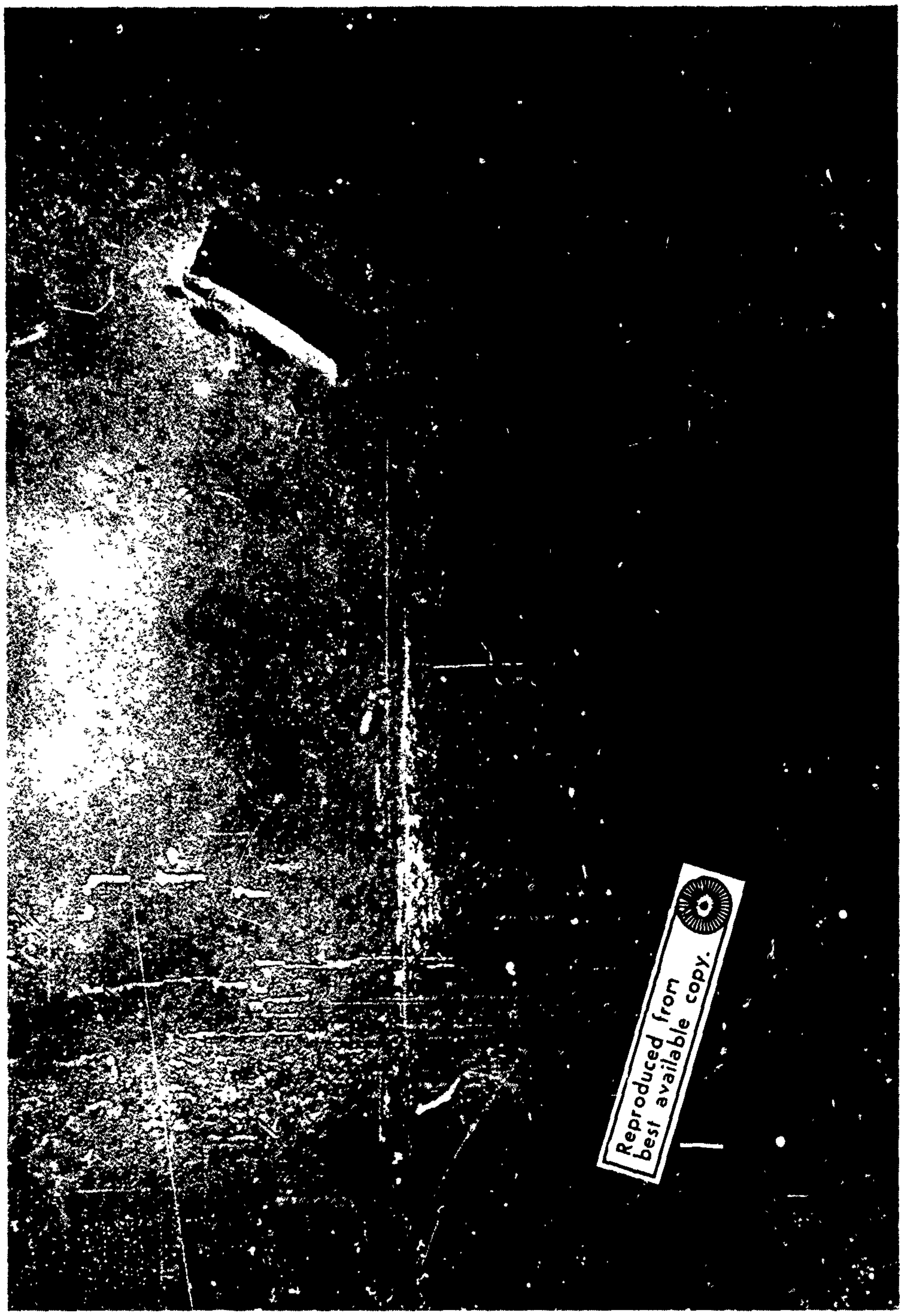


Fig. 12. Site 3, Run 1B, 0214, 15 July 1971.

Fig. 13. Site 3, Run 1B, 0216, 15 July 1971.

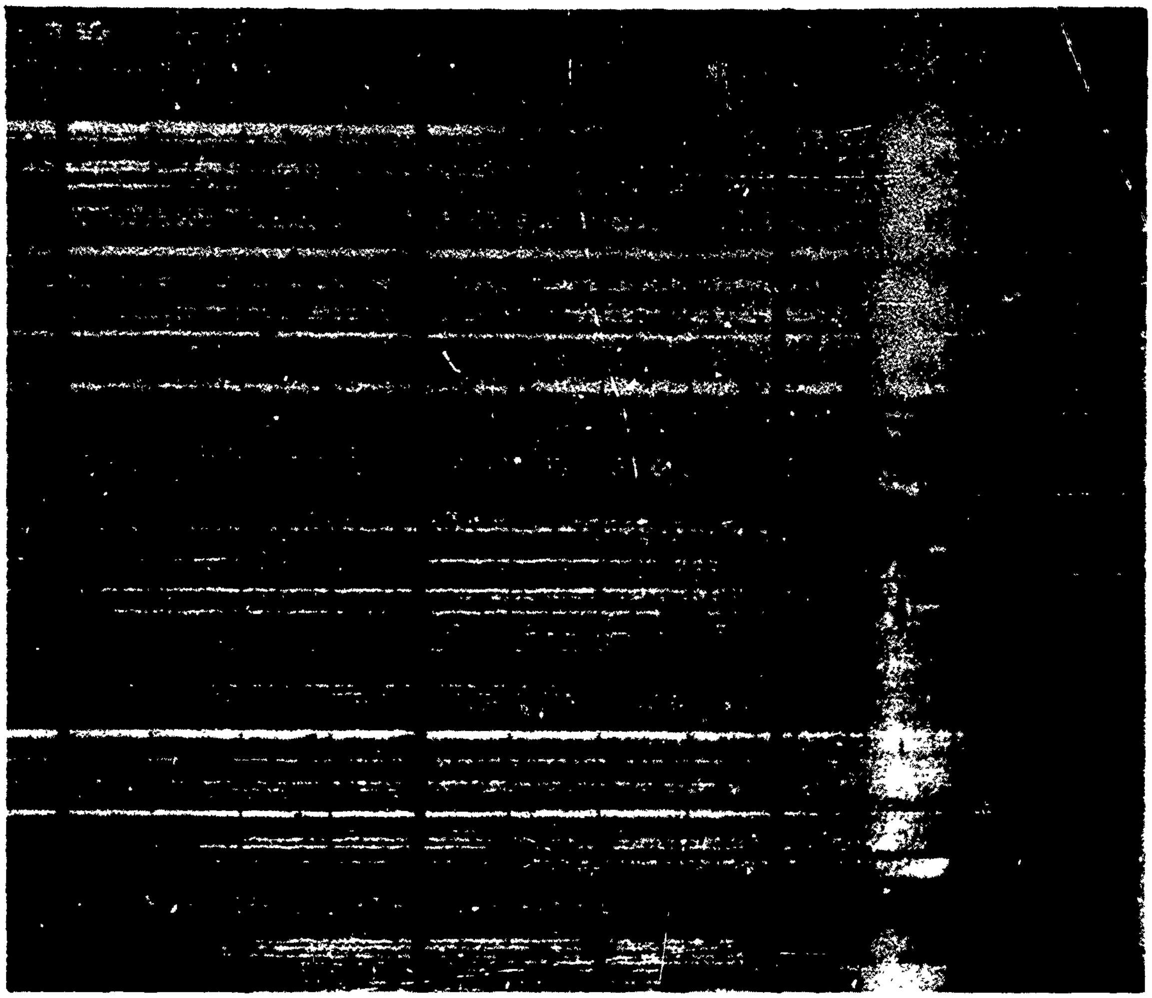


Fig. 14. Site 3, Run 1B, left side-looking sonar, 0200-0215, 15 July 1971.

METHOD OF DETERMINING FISH TRACK

The utilization of the information gained by side-looking sonar for wreckage site mapping is dependent upon knowledge of the precise position of the FISH. As stated previously, the navigation was accomplished relative to an array of six transponders developed at the Marine Physical Laboratory.[4/] The method of determining FISH and ship positions from interrogation of these transponders has been documented by Spiess et al.[5/] At sea the transponder ranges were fed into the shipboard PDP-11 computer to produce a rough plot of both the FISH and the ship. Further refinements were made ashore using the method described in the Preliminary Report.[3/] Final FISH positions were determined using a CDC 3600 computer. A total of 751 data points were used including 261 fixes of three or more transponder ranges. The root mean square residual range error was 2.08 meters (1.14 fathoms). This approaches the theoretical accuracy (about one fathom) of this transponder navigation system. The results, which incorporate a sound velocity factor to correct for the difference between the actual velocity of 1496 m/sec at the depth of the transponders and FISH, and the velocity of 1463 m/sec at which the recorders are calibrated, are presented in Table 1. All dimensions are in meters.

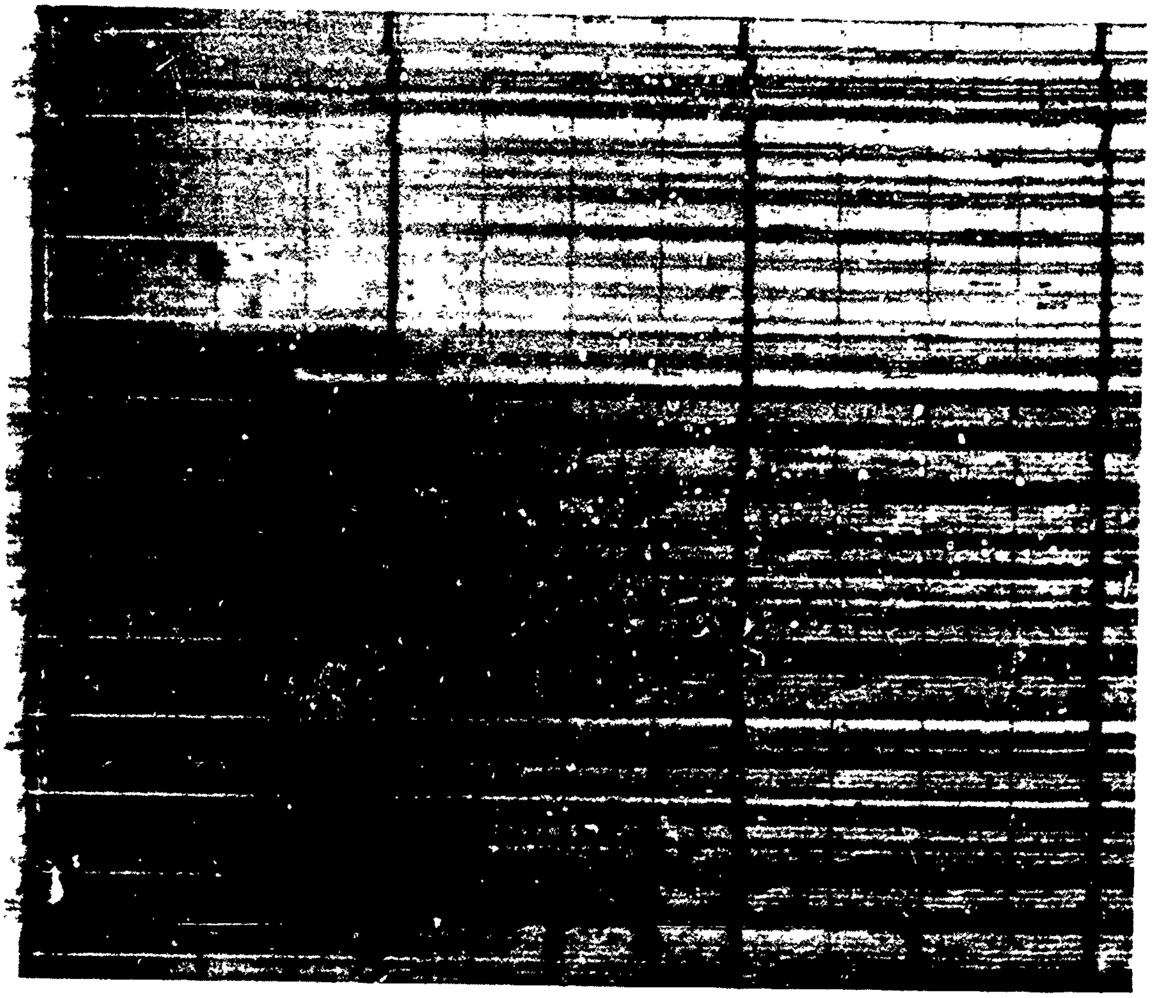


Fig. 15. Site 3, Run 1B, right side-looking sonar, 0200-0215, 15 July 1971.

The determination of latitude and longitude is dependent upon accurately positioning the ship in both Cartesian and geographical coordinates. The precision with which the coordinate transformation can be accomplished is dependent upon the accuracy to which the sound velocity profile can be determined as well as the accuracy of which the satellite navigation system is capable. The profile can be determined adequately from the literature, but in this case was calculated according to Wilson[6] using the actual temperature profile obtained from bathythermograph records and salinity values obtained from available hydrocast data. The ship-transponder navigation calculations utilized the sound velocity profile in a ray tracing process which compensates for both the effective sound velocity and refractive effects. The root mean square residual range uncertainty was 12.75 meters. The calculations could be further refined to reduce the residual error, however, this was not considered justified in view of the much larger uncertainty inherent in positions determined by the satellite navigation system.[7,8]

The standard deviation of satellite determined positions compared to transponder determined positions was 0.24 nautical mile. As can be expected[7] the latitude error was insignificant compared to that in the longitude plane. The former was 0.08 nautical mile, while the latter was 0.22 nautical mile.

The method of least squares was used to fit the satellite fixes to the transponder determined positions. The transformation placed the origin of the transponder network at latitude 48°15.8'N, longitude 127°00.2'W, with the Y-axis oriented along azimuth 013.7° True. Geographical coordinates of transponders and wreckage sites were then calculated using standard transformation equations. The results are presented in Tables 1 and 2.

Table 1. Transponder Locations
(X-Y coordinates in meters)

Code	X	Y	Latitude	Longitude
Green	804	3760	48°17.4'N	126°58.8'W
Red	4496	-3011	48°13.4'N	126°57.2'W
Blue	-1267	-1864	48°14.8'N	127°01.5'W
Purple	-6402	324	48°16.6'N	127°05.2 W
Brown 1	-2874	4155	48°18.1'N	127°01.6'W
Brown 2	-4906	3810	48°18.2'N	127°03.3'W

Table 2. Site Locations
(X-Y coordinates in meters)

Designation	X	Y	Approximate Dimensions and Orientations		Number of Useful Passes	Latitude	Longitude
#1	5094	-4277	400 m x 560 m	SE-NW	2	48°12.7'N	126°57.0'W
#2	-3508 ± 34	152 ± 65	580 m x 650 m	NE-SW	6	48°16.1'N	127°02.9'W
#3	-3278 ± 51	977 ± 54	600 m x 650 m	N-S	9	48°16.5'N	127°02.6'W
#4	572	-8423	390 m x 570 m	E-W	2	48°11.1'N	127°01.3'W
#5	3014	8613	270 m x 440 m	SE-NW	1	48°19.7'N	126°56.1'W

Note: The tolerances for Sites 2 and 3 coordinates are based upon the RMS average deviation of the individual pass coordinates from the averaged coordinates.

METHOD OF DETERMINING WRECKAGE SITE LOCATION AND GEOMETRY

The data in Table 2 were derived in the following manner. Examination of the side-looking sonar records established the dates and times of the passage of the FISH through or past the wreckage sites. The coordinates of the FISH at the times of commencement and completion of passage were then used to calculate the actual distance traversed (recalling that the FISH was not necessarily travelling at constant speed). This distance along the track then formed the basis for determining the time when the FISH passed abeam of the center of the track. This time was simply when half the distance had been traversed. The accuracy of this determination is heavily influenced by the clarity of the outline in the side-looking sonar record. The distances from the track to the near and far edges of the site were then measured and corrected for sound velocity and height of FISH off the bottom. The perpendicular distance from the track to the center of the site was taken to be the arithmetic mean of the distance to the near and far edges of the target area. If the FISH passed through a site then the distances referred to were determined from the composite of left and right side-looking sonars. The coordinates of the site center were calculated from the coordinates of the FISH at the time at which it passed abeam the site center, the perpendicular distance to the center at that time and the slope of the track.

Evaluation of the results revealed that very few of the side-looking sonar records clearly showed an entire site, and that consequently, multiple passes through a site were required to delineate its extent. In practical terms this meant that location, shape and size of Sites 2 and 3 could be determined with reasonable accuracy, but that these parameters could not be stated with as much assurance for the other three sites. The number of useful passes through or past a site, i.e., those for which valid navigational data were available, is indicated in Table 2.

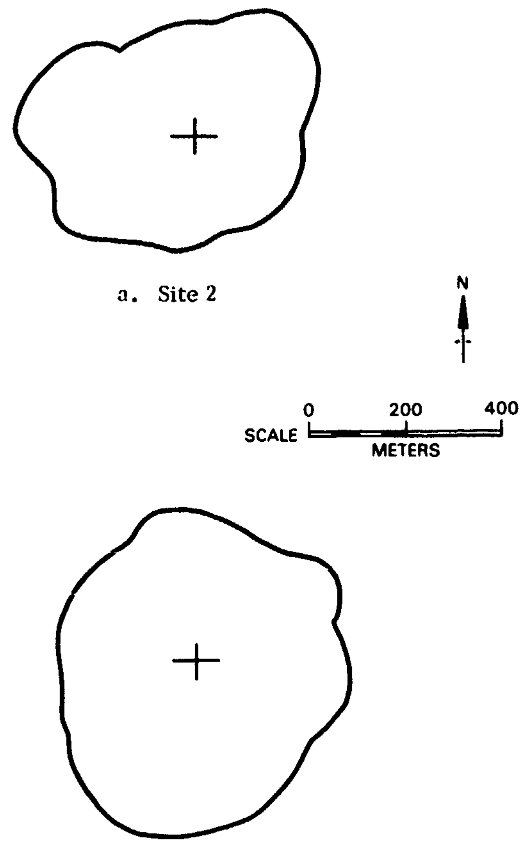
The coordinates listed for the centers of Sites 2 and 3 are the average of the coordinates calculated for each pass. They correlate very well with those passes that show a clear outline of the site in the side-looking sonar records. These are, for Site 2, 0630 14 July, coordinates X: -3518, Y: 147, and for Site 3, 0205 15 July, coordinates X: -3276, Y: 956. The size and shape of the site as seen on these passes also correlate well with the composite reconstruction of these sites.

The composites, Fig. 16a and b, were constructed by plotting the apparent site center, distance along track and the near and far edges for each pass. The plots were overlaid and the outline was thus generated. A perhaps more accurate picture of the sites would be obtained by fairing the edges. This was not done, however, in order to provide an accurate presentation of actual area coverage. As each individual pass was plotted every point of intersection with the track was noted and checked to ensure that no transit through the area had been overlooked. This step also served as a checkupon navigation. As an illustrative example, if the plot of Site 2 from pass number 6 (0630 14 July) intersected the track between 0136 and 0149 on 15 July, the side-looking sonar record for that period of time was checked to see if the site had been recorded and to see if these times were the limits of that transit. Correlation was excellent in all cases for Sites 2, 3 and 4.

The composites clearly indicate that the wreckage sites are:

a) Larger than previously supposed.
b) Similar in dimensions.
c) Nearly circular in shape.

Insufficient data are available to be precise about the remaining sites, but in view of the findings with regard to Sites 2 and 3 it is strongly suggested that the dimensions are similar. The dimensional data taken along the track tend to support this hypothesis; the dimensional data perpendicular to the track are indicative of a more pronounced elliptical shape. The latter is probably due to the limits of the side-looking sonar sweep width. The data in Table 2 for Sites 1, 4 and 5 are provided with the understanding that they describe only the minimum area covered by the wreckage.



a. Site 2

b. Site 3

Fig. 16. Composite outlines.

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This operation was put together on very short notice and could not have been successful without the cooperation of many people both inside and outside of the Marine Physical Laboratory. Within our own organization we relied most heavily on Carl Lowenstein for our computer capability and Tony Boegeman for the health and welfare of the deep tow equipment. In addition we had the help of Phil Rapp for photo processing, John Mudie for scientific background support and Bud Mundy and his assistants for working out the necessary ad hoc arrangements for handling the FISH from USNS DE STEIGUER — a ship on which we had never previously operated. Captain Reed and his group in the Oceanographer of the Navy's staff kept things moving administratively while the Pacific Support Group of the Naval Oceanographic Office, particularly in the person of their on-board representative, Carey Ingram, provided invaluable direct assistance and liaison. Finally, we are indebted to the commanding officer of USNS DE STEIGUER, Captain J. R. Hosey, and his ship's force for their fine cooperation and support. The scientific party that did the work is pictured in Fig. 17 and listed in the caption.

Fig. 17. Scientific party. Kneeling (left to right): C. Ingram, J. Mather. Standing (left to right): R. Wright, C. Lowenstein, J. Donovan, F. Spiess, D. Boegeman, M. McGehee, K. Klitgord, J. Mudie, B. Malfait, P. Rapp, S. Sanders (partially hidden), R. Tyce, J. Alderete.

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A deep towed submersible instrument platform (FISH) equipped with side-looking sonar, magnetometer and cameras was used to locate and document the wreckage sites of five munitions laden ships which had been detonated in the process of munitions disposal. Geographical positions were determined first with reference to a network of acoustic transponders planted for this purpose. Subsequently the latitude and longitude of the transponders were determined by correlating the towing vessel's position as determined by satellite navigation with the corresponding position relative to the transponder network. Wreckage sites were then assigned conventional geographical coordinates. Photographs were taken of all sites, and for comparison purposes, of undisturbed sea floor.

IV. Ocean Engineering

1. F. N. Spiess
2. S. M. Sanders

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